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and  
membrane dehydration element packaged into a complicated assembly with little or no associated cost reduction. Thus there still remains a need in the art for an improved gas-conditioning device that simultaneously removes suspended matter and dehydrates the gas.

In paragraph [0008]:

[0008] A more preferred hollow fiber membrane cartridge includes:

- A2  
PRTS  
12/05/02
- a) an elongated tubular inner core member,
  - b) a substantially cylindrical hollow fiber membrane bundle surrounding said inner core member constructed from hollow fiber membranes having permeate and nonpermeate sides, said bundle being characterized as having a substantially countercurrent flow arrangement between the gas flow on said permeate side and the gas flow on said nonpermeate side,
  - c) two tubular tubesheets encapsulating both ends of the ~~said~~ hollow fiber bundle in a fluid-tight arrangement with one end of the inner core member opening out of one of the tubesheets to permit flow of gas in and out of said inner core member and wherein at least one of said tubesheets is severed to permit an unobstructed flow of gas in and out of the hollow fiber lumens; and,
  - d) a shell and at least one end closure surrounding said hollow fiber membrane bundle.

In paragraph [0010]:

[0010] According to another preferred embodiment of this invention, the above objectives and other objectives that are apparent to those skilled in the art are achieved by providing a gas purification apparatus comprising:

- A3
- a) a housing body defined by first and second essentially cylindrical bowls or shells connected in a sealed and removable manner in correspondence to their axial end portion to a common head closure member being interposed therebetween, said first and second bowls or shells defining a lower internal chamber and upper internal chamber within said housing, wherein said head closure having formed therethrough a feed gas inlet port in a first end of said head closure and a product outlet port in a second end of said head closure, such that said inlet port and said outlet port are spaced essentially in a straight line, and at least one gas transport conduit in fluid communication with said upper and lower internal chambers and wherein said first

bowl or shell and said second bowl or shell being provided with at least one waste fluid exit port,

93 b) a gas filtration element adapted to separate liquid and solid particles from incoming gas passing therethrough disposed in said lower chamber, and

c) a substantially cylindrical hollow fiber membrane cartridge adapted to separate water vapor from incoming gas passing therethrough disposed in said upper chamber.

In paragraph [0020]

94 [0020] This invention provides for gas purification processes that utilize the disclosed novel integral membrane gas dehydration/filtration apparatus. The gas purification processes of this invention are designed to remove suspended matter from gas, including, but not limited to oil, water droplets, dust, and/or water vapor through the use of a singular integral device. In a preferred embodiment, the device comprises at least one gas filtration element and a hollow fiber membrane gas dehydration cartridge placed coaxially in a common, substantially cylindrical housing. The filtration element can partially or completely surround the membrane cartridge; alternatively it can be placed internal to the membrane cartridge or, in yet another alternative it can be placed below the membrane cartridge in a coaxial arrangement. In some embodiments, the gas filtration element is omitted and a single gas filtration/gas separation hollow fiber membrane cartridge is utilized. Furthermore, in some instances a cyclone separator or deflector is disposed in front of the filtration element to aid in the removal of oil and water droplets. In some embodiments, the filtration element and the membrane cartridge are placed coaxially around a central tubular core member that can be a common core member wherein the filtration element and the membrane cartridge abut each other. The filtration element and the hollow fiber membrane cartridge are preferably removably attached. Accordingly it is not necessary to carry out time consuming disassembly of the clogged filter element into the component parts. Rather, the casing of the gas purification assembly of this invention can be easily opened to detach the clogged filtration element for replacement purposes. The gas filtration element is typically positioned upstream of the membrane dehydration element so that the life of the membrane dehydration element can be extended. However, in some embodiments, a particulate filter can be also placed downstream of the membrane cartridge as a polishing filter.

In paragraph [0031]:

95 [0031] The hollow fiber membrane cartridge 104 comprises an annular hollow fiber membrane bundle 116 arranged around the hollow core tube member 118, surrounded by shell 117 and axial end closures or caps 120 and 121. The bundle 116 is formed by a multiplicity of hollow fiber membranes uniformly arranged around the tubular member 118. One preferred method of forming a uniformly structured hollow fiber bundle is by winding the hollow fibers around the tubular member 118. Both ends of the hollow fiber membrane bundle 116 are encapsulated in tubesheets 119 and 124 in a fluid-tight arrangement with one end of the inner core tube member 118 opening out of the tubesheet 124. The tubesheet ends are severed to allow for unobstructed gas flow from and into the hollow fiber lumens. The exposed hollow fiber membrane bundle between the tubesheets 119 and 124 may be encased, as shown in Fig. 1, with an essentially nonpermeable film barrier or a wrap 123 except for a non-encased circumferential region or gap 122 adjacent to the tubesheet 119. The wrap 123 is designed to improve the uniformity of gas flow through the bundle and to ease its installation into the external shell 117. The gas flow passageways in the membrane cartridge 104 are arranged to provide for a thermodynamically efficient countercurrent flow arrangement between the feed/nonpermeate stream on the shell side and the permeate/sweep stream on the lumen side of the hollow fiber membranes, respectively. The feed gas is introduced into the hollow fiber bundle 116 through openings 125 in the shell 117 and the gap 122 and the nonpermeate product gas is removed through openings 126 in the core tube member 118. The openings 125 and 126 are positioned adjacent to the tubesheets 119 and 124, respectively. The permeate gas is withdrawn through the open ends of the hollow fiber lumens on the axial surface of the tubesheet 119. This flow arrangement ensures a substantially countercurrent flow of the feed gas with respect to the permeate gas. The cartridge 104 is further equipped with a flow-control orifice 127 that provides for introduction of a fraction of the nonpermeate gas as a sweep. The placement of the orifice 127 can be located inside or outside the tubesheet, furthermore, it can be omitted from the embodiments that do not require the use of the sweep gas internal to the cartridge.

In paragraph [0034]

96 [0034] Referring to Fig. 2 there is shown a sectional view of another embodiment of a gas purification apparatus according to this invention. The gas purification apparatus 201 comprises an

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outer housing body 202 comprising a bowl or shell body member 204 and a head closure member 205, and a hollow fiber membrane gas separation cartridge 203, the membrane cartridge is positioned within the housing body. The housing body includes a bowl or shell body member 204 and a head closure member 205. The bowl or shell body is essentially cylindrical in shape and is connected in a sealed and removable manner to the head closure member 205. The head closure connects to the axial-end portion of the bowl or shell by threads or by a bayonet connector, as shown in Fig. 2, or by any other fluid-tight sealing arrangement. The head closure 205 contains a feed gas inlet port 206, a purified gas outlet port 207, and gas transfer conduits 210 and 211. The feed and product gas ports are formed in a first and second end of the head closure 205 and are spaced essentially in a straight line relative to one another. The gas transfer conduit 210 is positioned coaxially to the housing body. The gas transfer conduits 210 and 211 are in fluid communication with the feed and product ports, respectively.

In paragraph [0038]:

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[0038] This can be accomplished by co-winding monofilaments at a different packing density along the axial length of the bundle as described above and/or by varying the wind angle of the hollow fibers or monofilaments along the axial length of the bundle, or by a combination of the above methods and other methods well known in the art. The variable angle winding process is disclosed in the above referenced US Patent 5,837,033. Both ends of the hollow fiber membrane bundle 215 are encapsulated in tubesheets 219 and 221 in a fluid-tight arrangement with one end of the inner core tube member 216 opening out of the tubesheet 220. The tubesheet ends are severed to allow for unobstructed gas flow from and into the hollow fiber lumens. The exposed hollow fiber membrane bundle between the tubesheets 219 and 221 may be encased, as shown in Fig. 2, with an essentially nonpermeable film barrier or a wrap 222 except for a non-encased circumferential region or gap 223 adjacent to the tubesheet 219. The wrap 223 is designed to improve uniformity of gas flow through the bundle and to ease its installation into the external shell 217. The gas flow passageways in the membrane cartridge 203 are arranged to provide for a thermodynamically efficient countercurrent flow arrangement between the feed/ nonpermeate stream on the shell side and the permeate/ sweep stream on the lumen side of the hollow fiber membranes, respectively. The feed gas is introduced into the hollow fiber bundle 216 through openings 225

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cont in the shell 217 and the nonpermeate product gas is removed through openings 226 in the tubular core member 216. The openings 225 and 226 are positioned adjacent to the tubesheet 219 and 221, respectively. The lower row of openings 225 is also utilized to remove entrained liquids from the cartridge 203. The permeate gas is withdrawn through the open ends of the hollow fiber lumens on the axial surface of the tubesheet 219. This flow arrangement ensures a substantially countercurrent flow of the feed gas with respect to the permeate gas. The cartridge 203 is further equipped with a flow-control orifice 230 placed in the tubesheet 221 that provides for introduction of a fraction of the nonpermeate gas as a sweep. The placement of the orifice 230 can be inside or outside the tubesheet, furthermore it can be omitted from the embodiments that do not require the use of the sweep gas internal to the cartridge.

In paragraph [0039]:

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[0039] In the gas purification/separation process of this invention the feed gas is introduced into the apparatus 201 through the feed port 206 that connects to the gas transport conduit 211. The feed gas is channeled through openings 225 into the shell side of the hollow fiber membrane bundle 215 wherein the feed gas is brought into contact with the exterior of hollow fiber membranes. The feed gas is transported through the filtration media formed by the structured hollow fibers wherein the suspended matter is removed, while simultaneously the feed gas is stripped of undesirable gaseous impurities, such as water vapor, that were removed by permeation into the hollow fiber lumens. The purified gas is then transported through openings 226 in the tubular core member into the gas transfer conduit 220 and is then collected as a product nonpermeate gas through the exit port 207. A fraction of the nonpermeate gas is directed through the orifice 230 into the hollow fiber lumens and is used as a sweep gas on the permeate side of the hollow fibers. The combined permeate/flow stream is removed from the apparatus as a waste gas through the port 212. The liquid removed by the filtration action of the hollow fiber cartridge 203 is collected at the bottom of the bowl or shell 204 and is removed through the waste fluid port 212 intermittently. The orifice 230 is an interchangeable flow-control orifice that is sized to allow a predetermined amount of nonpermeate gas to be used as a sweep. The amount of sweep gas in turn determines the level of product purity. The sweep gas flow rate is frequently 5% to about 30% of the net flow rate of the nonpermeate gas. The apparatus shown in Fig. 2 utilizes a hollow fiber membrane

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60C cartridge wherein the feed gas is introduced external to the cartridge and the nonpermeate gas is withdrawn internal to the cartridge.

In paragraph [0043]:

99 [0043] The hollow fiber membrane cartridge 304 comprises an annular hollow fiber membrane bundle 316 arranged around the hollow core tube member 315, surrounded by shell 317 and axial end closures or caps 320 and 321. The bundle 316 is formed by a multiplicity of hollow fiber membranes uniformly arranged around the tubular member 315. One preferred method of forming a uniformly structured hollow fiber bundle is by winding the hollow fibers around the tubular member 315. Both ends of the hollow fiber membrane bundle 316 are encapsulated in tubesheets 318 and 324 in a fluid-tight arrangement with one end of the inner core tube member 315 opening out of the tubesheet 318. The tubesheet ends are severed to allow for unobstructed gas flow from and into the hollow fiber lumens. The exposed hollow fiber membrane bundle between the tubesheets 318 and 324 may be encased, as shown in Fig. 3, with an essentially nonpermeable film barrier or a wrap 323 except for a non-encased circumferential region or gap 322 adjacent to the tubesheet 319. The wrap 323 is designed to improve uniformity of gas flow through the bundle and to ease its installation into the external shell 317. The gas flow passageways in the membrane cartridge 304 are arranged to provide for a thermodynamically efficient countercurrent flow arrangement between the feed/nonpermeate stream on the shell side and the permeate/sweep stream on the lumen side of the hollow fiber membranes, respectively. The feed gas is introduced into the hollow fiber bundle 316 through openings 325 in the tubular core member 315 and the nonpermeate product gas is removed through the gap 322 and openings 326 in the external shell 317. The openings 325 and 326 are positioned adjacent to the tubesheet 324 and 318, respectively. The permeate gas is withdrawn through the open ends of the hollow fiber lumens on the axial surface of the tubesheet 324. This flow arrangement ensures a substantially countercurrent flow of the feed gas with respect to the permeate gas. The cartridge 304 is further equipped with a flow-control orifice 327 that provides for introduction of a fraction of the nonpermeate gas as a sweep. The orifice 327 is preferably a replaceable orifice attached to the cap 320 by a thread or a similar detachable arrangement. The placement of the orifice 327 can be omitted from the embodiments that do not require the use of the sweep gas internal to the cartridge. Furthermore,

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cont. the cartridge 304 shown in Fig. 3 can be converted from a cartridge that utilizes the sweep to a cartridge that does not utilize the sweep by sealing the gas passageway in the orifice 327 with a stopper.

In paragraph [[0044]]:

910 [0044] In the gas purification/separation process of this invention the feed gas is introduced into the apparatus 301 through the feed port 308 that connects to the hollow gas transport conduit 311. The gas is transported through the filtration media of the filtration element 303 wherein the suspended matter is removed. The thus filtered gas is then transported through conduit 310 into the inner core member 315. The feed gas is channeled through openings 325 into the shell side of the hollow fiber membrane bundle 316 wherein the feed gas is brought into contact with the exterior of hollow fiber membranes. The feed gas stripped of undesirable gaseous impurities, such as water vapor, that were removed by permeation into the hollow fiber lumens is then transported through the gap 322 and openings 326 in the exterior cartridge shell and is collected as a product nonpermeate gas through the exit port 309. A fraction of the nonpermeate gas is directed through the orifice 327 into the hollow fiber lumens and is used as a sweep gas on the permeate side of the hollow fibers. The combined permeate/flow stream is removed from the apparatus as a waste gas through the port 319. The liquid removed by the filtration element 303 is collected at the bottom of the bowl or shell 305 and is removed through the liquid waste port 326 intermittently. The orifice 327 is an interchangeable flow-control orifice that is sized to allow a predetermined amount of nonpermeate gas to be used as a sweep. The amount of sweep gas in turn determines the level of product purity. The sweep gas flow rate is frequently 5% to about 30% of the net flow rate of the nonpermeate gas. The advantageous feature of the cartridge is that the same cartridge can be used to generate different purity products by simply changing the size of the orifice. The cartridge can be used for gas separation applications that do not require the use of sweep gas by simply blocking or eliminating the orifice 327.